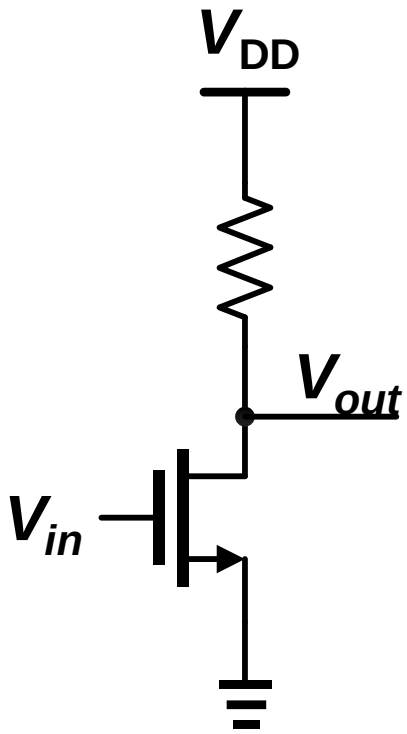
MOSFET Differential Pair With Active Load

Hanwool Jeong

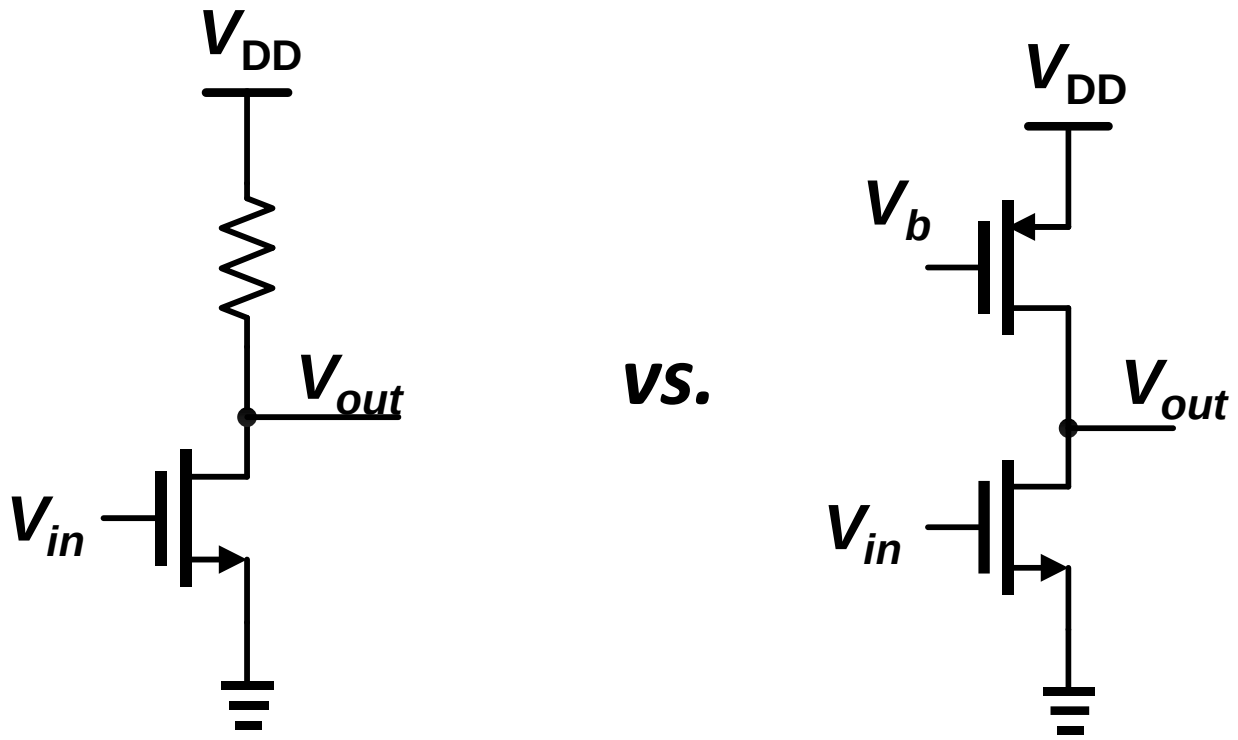
hwjeong@kw.ac.kr

Background; Load?

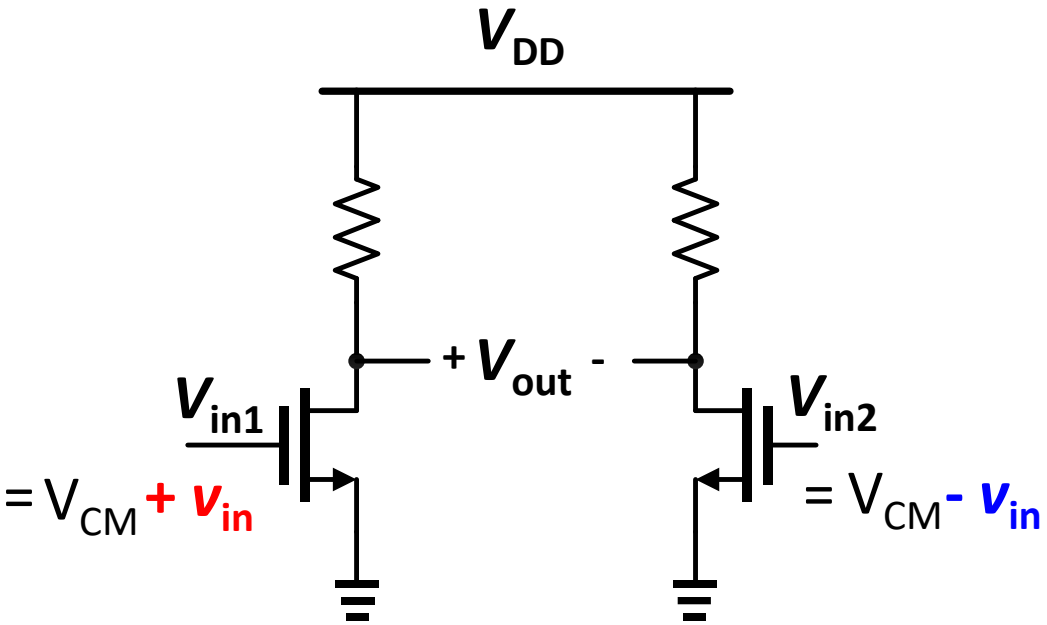
- What does mean “load” in a circuit?

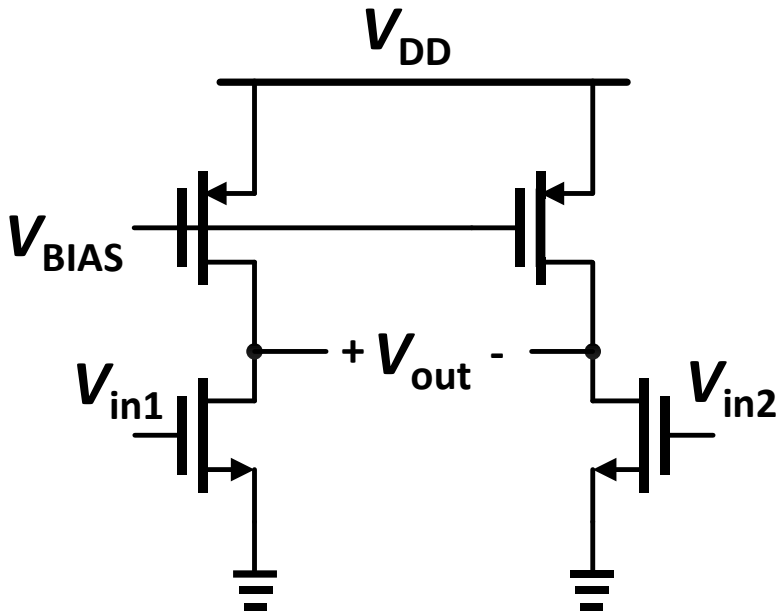


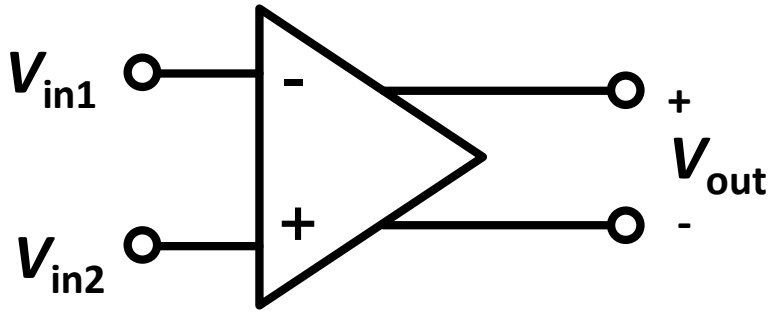
Background; Active vs. Passive



Revisit Differential Pair

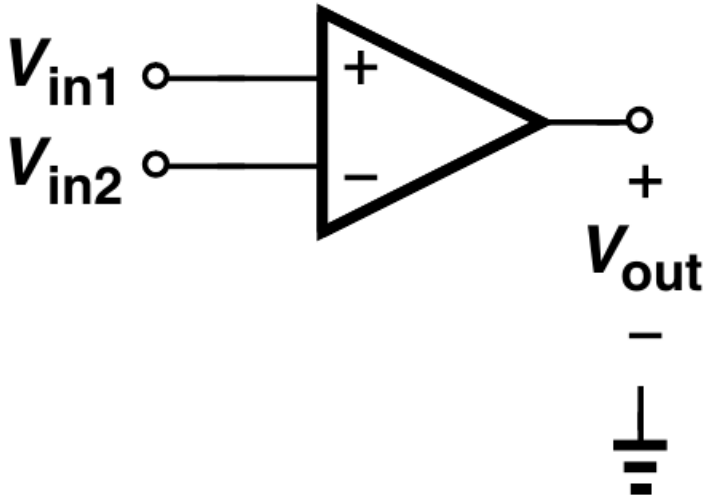






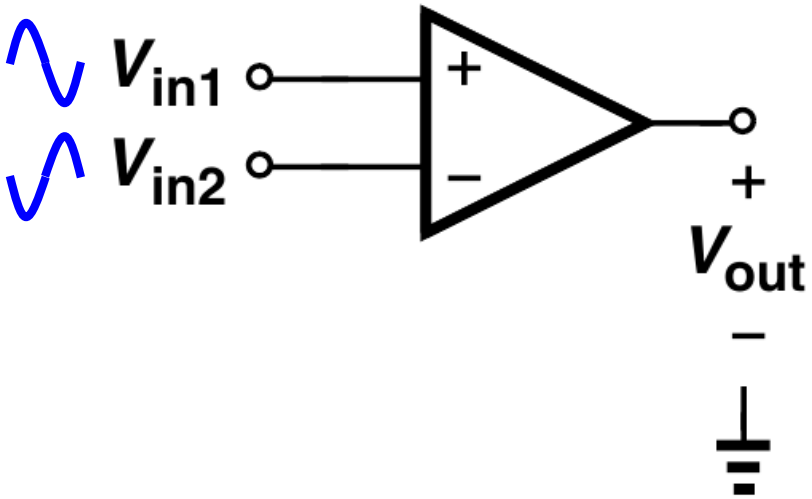
Motivation

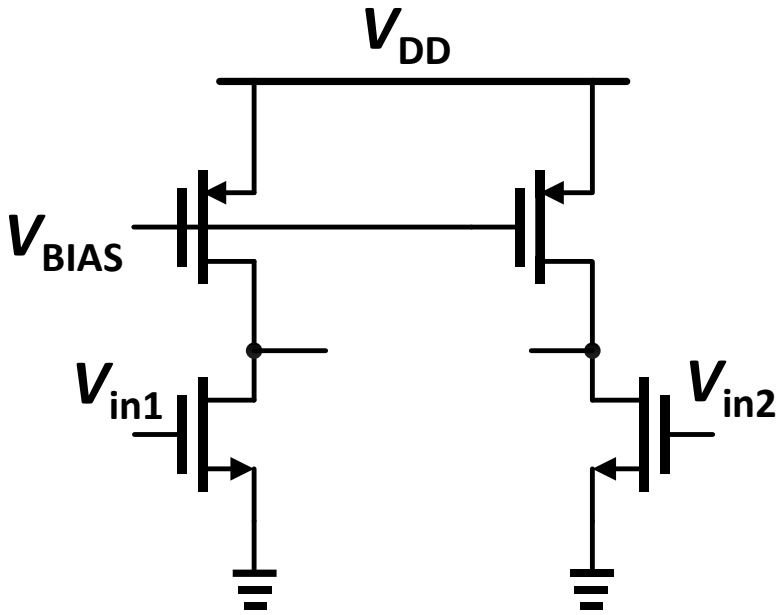
- How about this? Differential input into single-ended output



Starting From Differential Pair

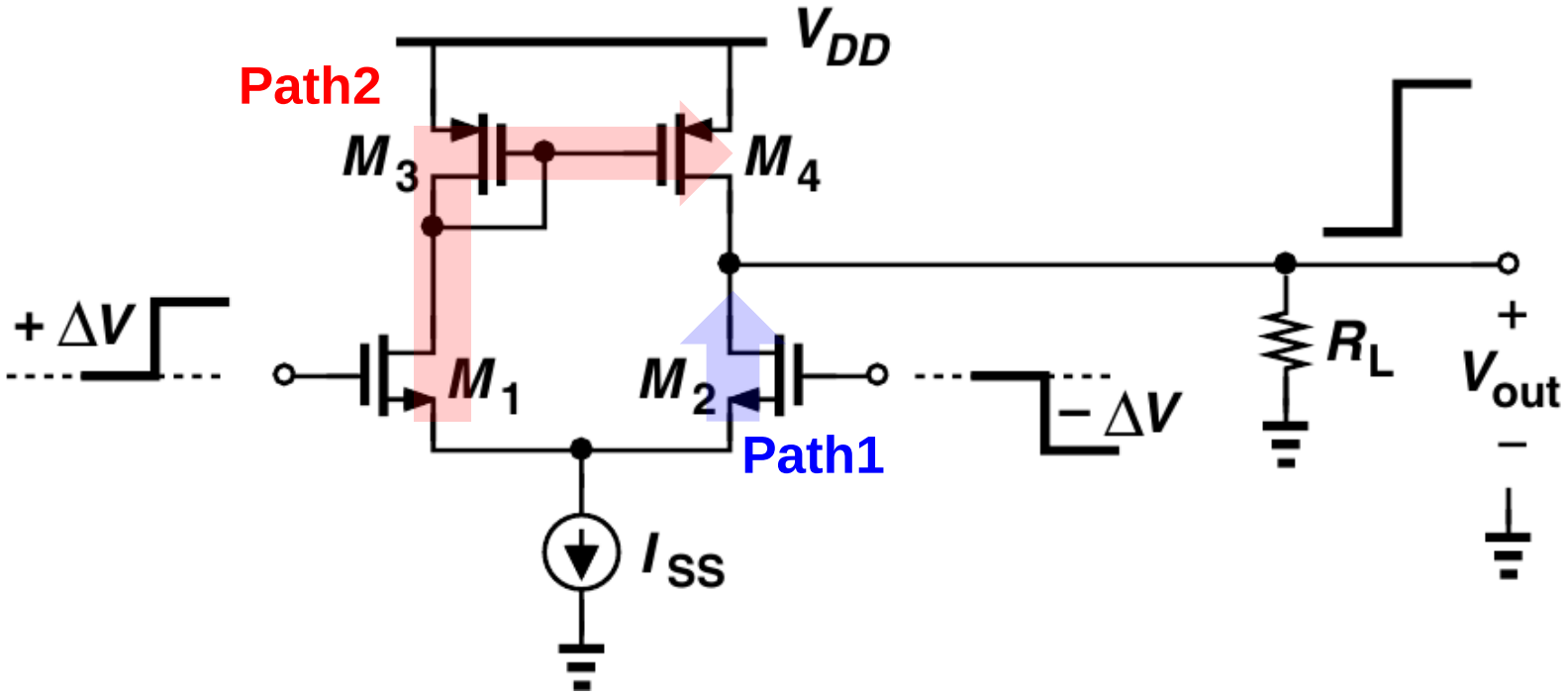
- How can you implement differential input to single-ended output amplifier?





MOSFET Differential Pair with Active Load

- There are two paths incurring V_{out}.

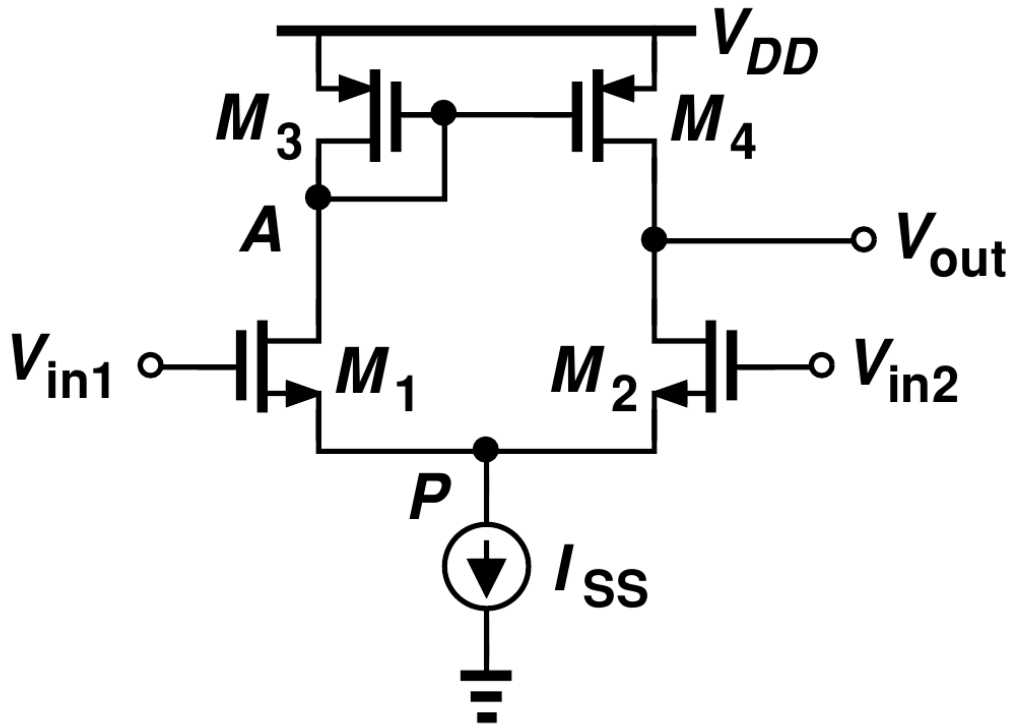


➔ **Can you determine the exact gain quantitatively?**

Can We Utilize Half Circuit?

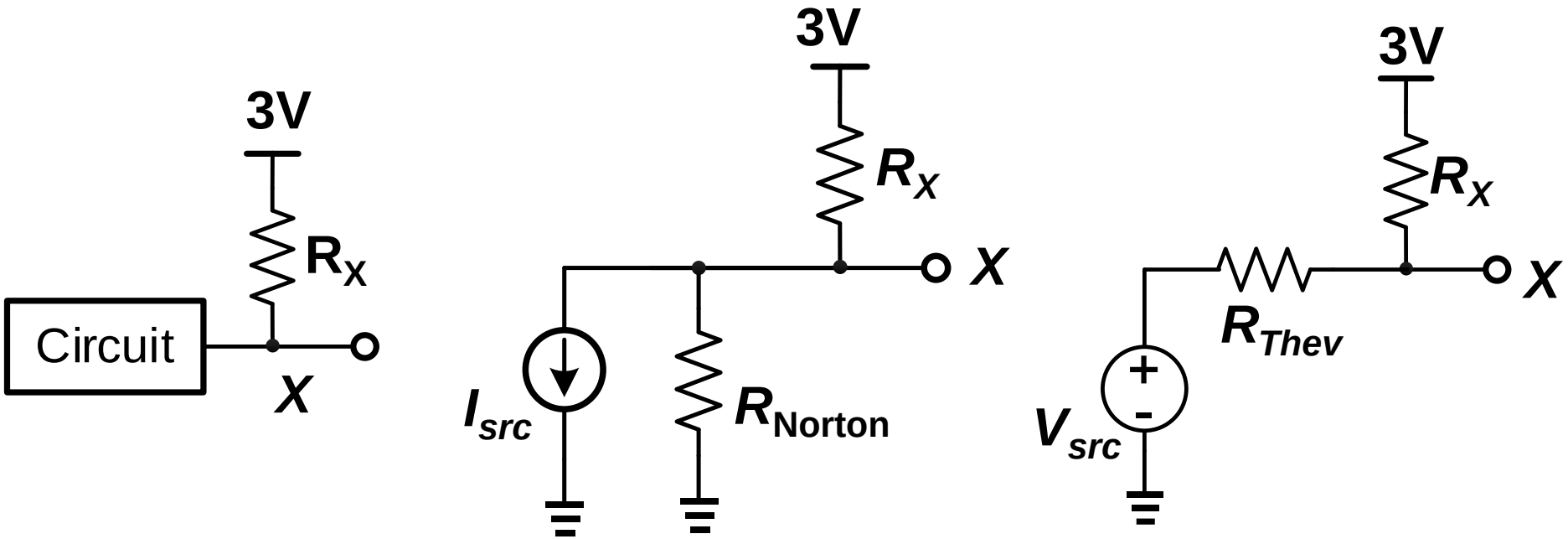
- NO. The circuit is asymmetric.

➔ We can't consider the *P* node as ground



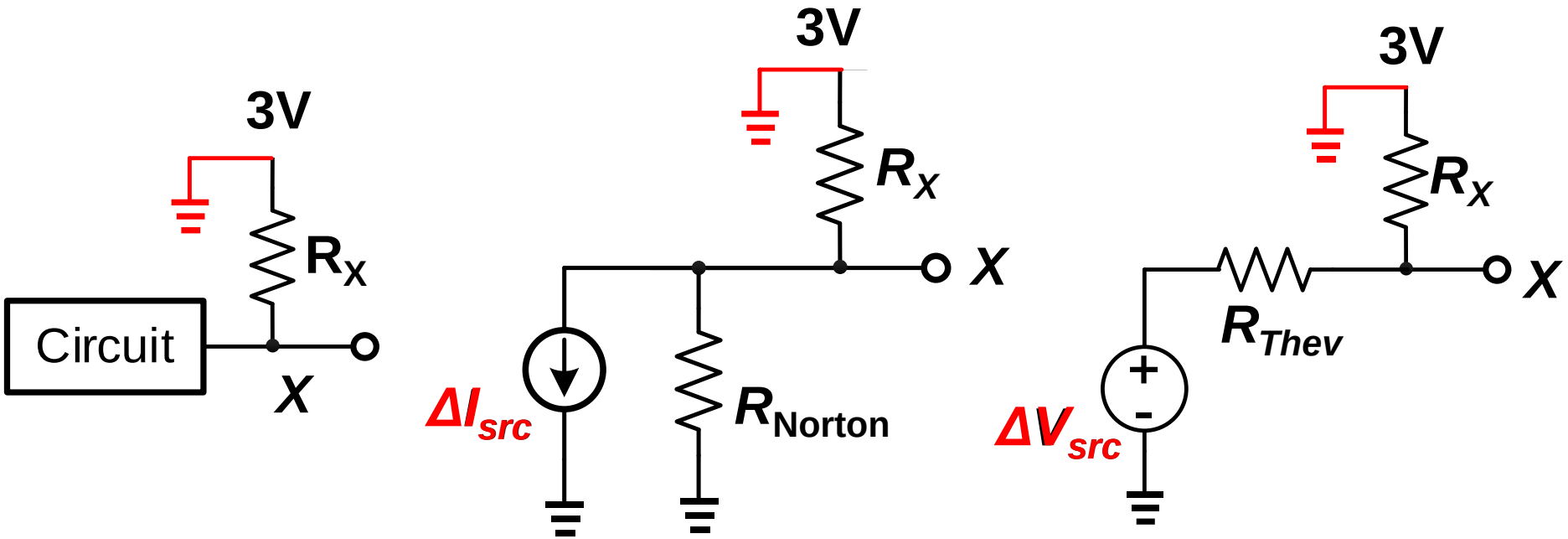
Low Impedance vs. High Impedance

- How can the node X change freely responding to external shock?
- How much does the node X change freely according to change in the external current/voltage voltage?



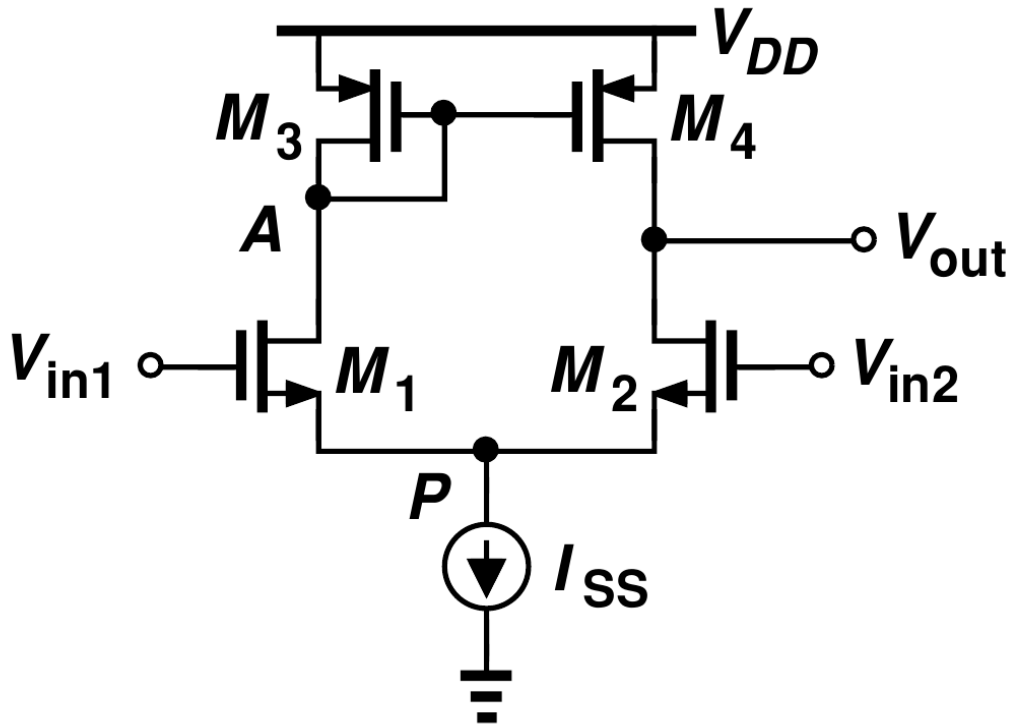
For Small Signal Analysis?

- Only V/I change matter, and transistor can be linearized and can be replaced with current source & resistances
- Useful to specify "**impedance**" of the nodes.



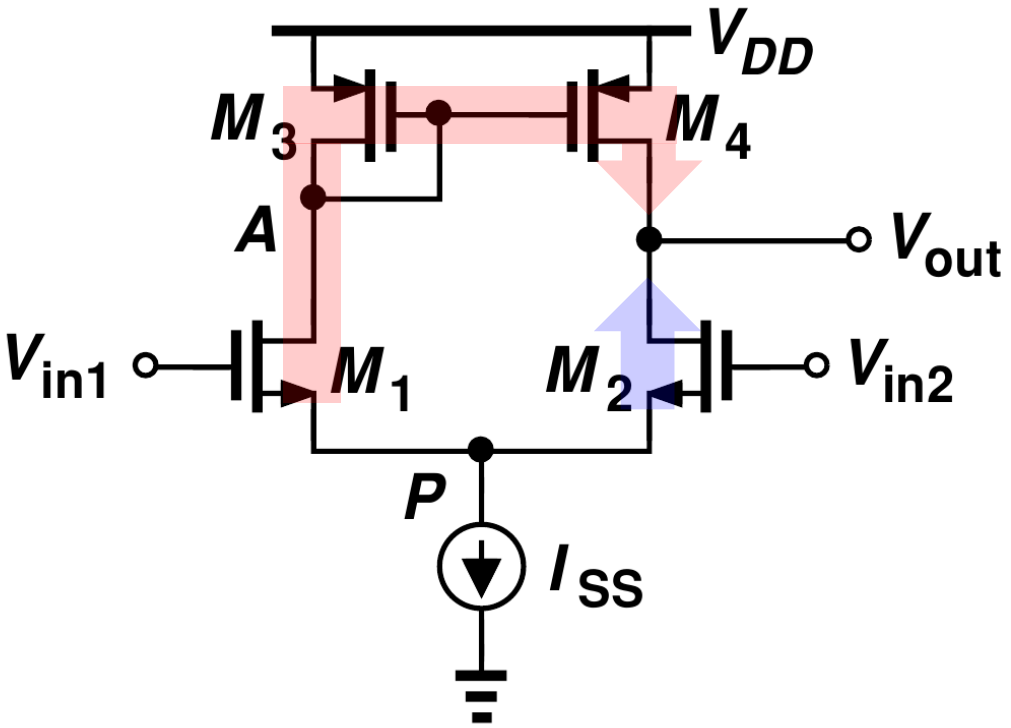
Asymmetry in Terms of Node A vs. V_{out}

- We can say that the circuit asymmetry comes from
  - The node A has low impedance
  - The node Vout has high impedance



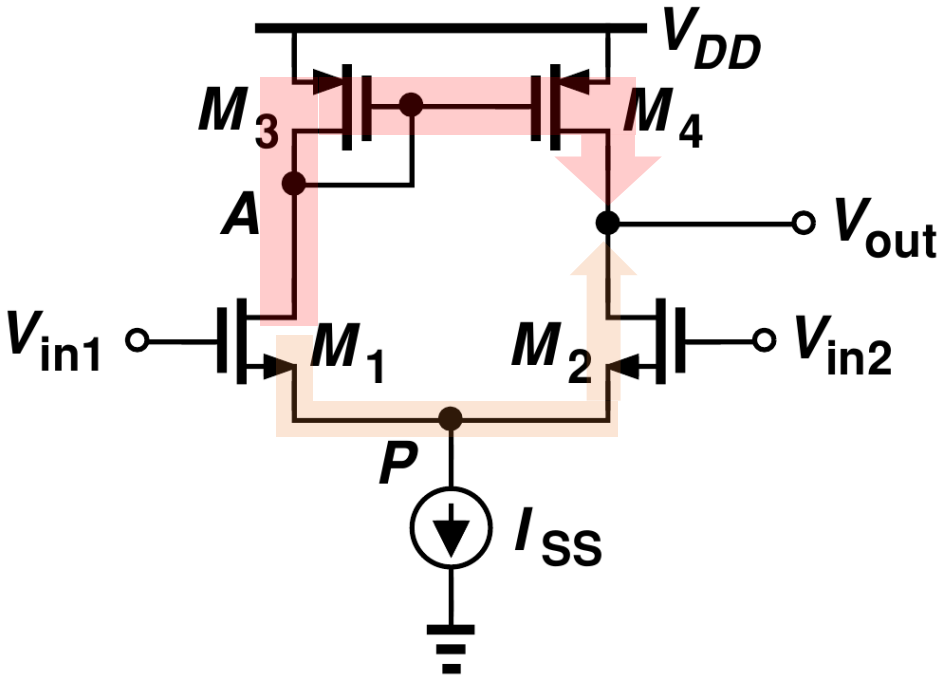
Effect of V_{in1} & V_{in2} on V_{out} (1)

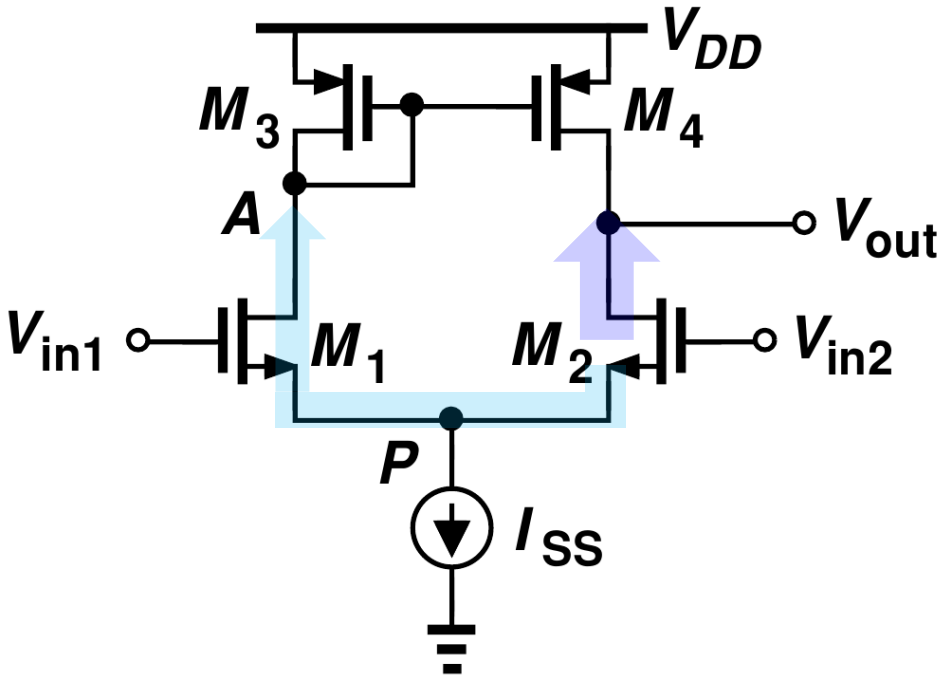
- $V_{in1}\uparrow$ ➔ $V_A\downarrow$ ➔ V_{GS} of M4 $\downarrow$ ➔ I_{DS} of M4$\uparrow$ ➔ $V_{out}\uparrow$
- $V_{in2}\downarrow$ ➔ $V_{out}\uparrow$
- Are above two all things to consider?



Effect of V_{in1} & V_{in2} on V_{out} (2)

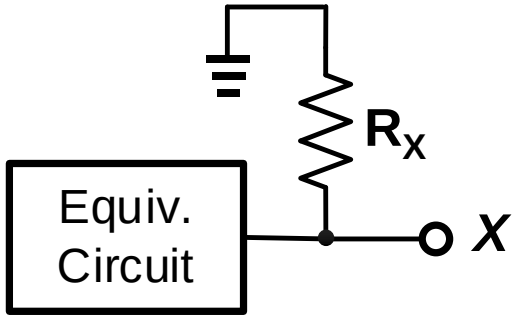
- $V_{in1}\uparrow$ ➔ $V_A\downarrow$ ➔ V_{GS} of M4 $\downarrow$ ➔ I_{DS} of M4$\uparrow$ ➔ $V_{out}\uparrow$: A ➔ M4 ➔ V_{out}
  ➔ $V_p\uparrow$ ➔ $V_{out}\uparrow$: M2 ➔ V_{out}
- $V_{in2}\downarrow$ ➔ $V_{out}\uparrow$: M2 ➔ V_{out}
  ➔ $V_P\downarrow$ ➔ $V_A\downarrow$ ➔ V_{GS} of M4 $\downarrow$ ➔ I_{DS} of M4$\uparrow$ ➔ $V_{out}\uparrow$: A ➔ M4 ➔ V_{out}

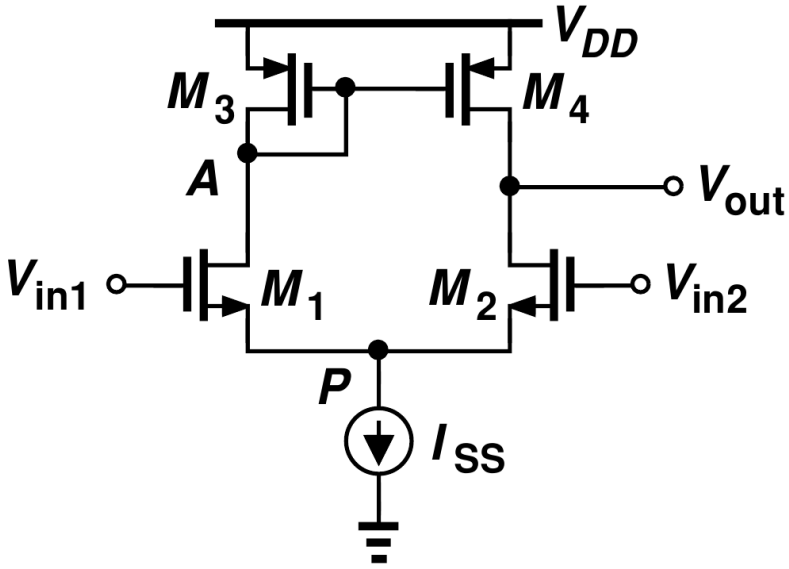




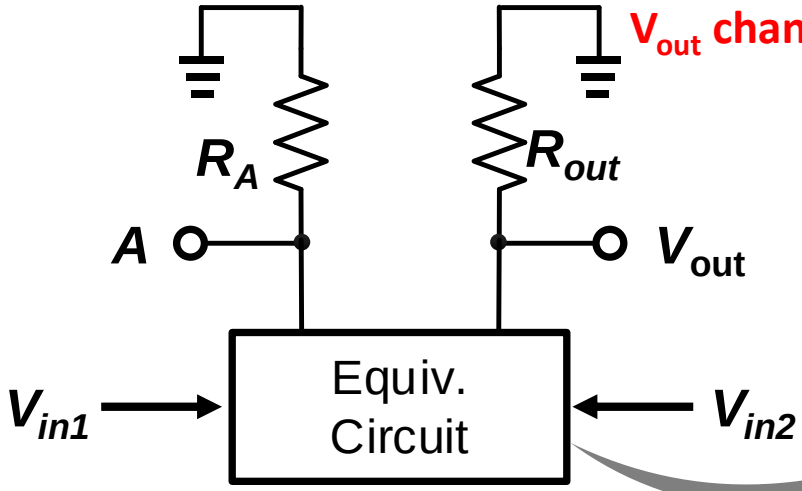
Applying Equivalent Circuit

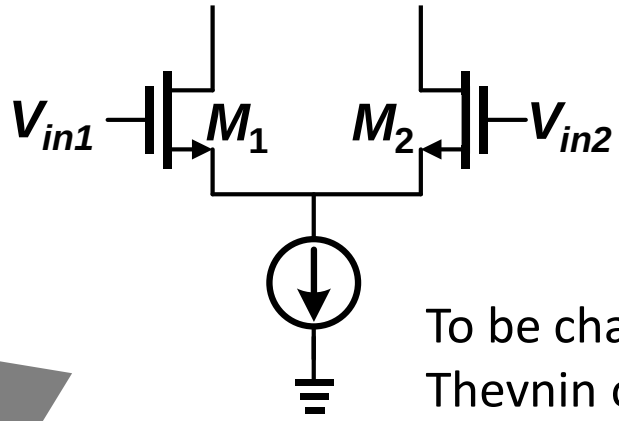
- And apply to our case.





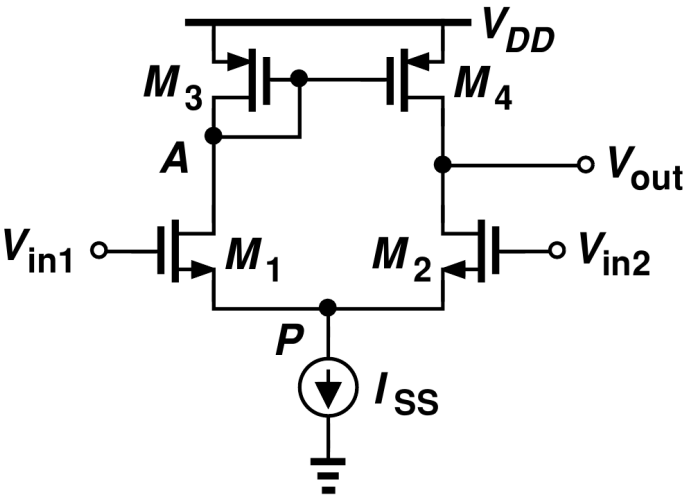
We should model V_{out} change by A

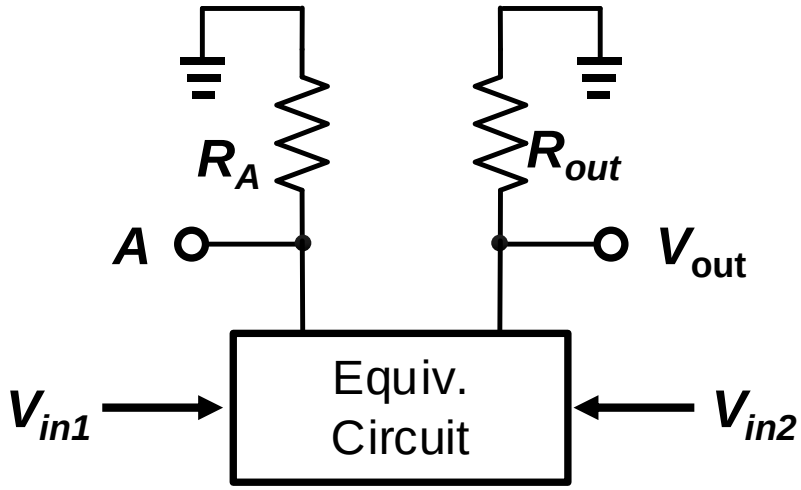


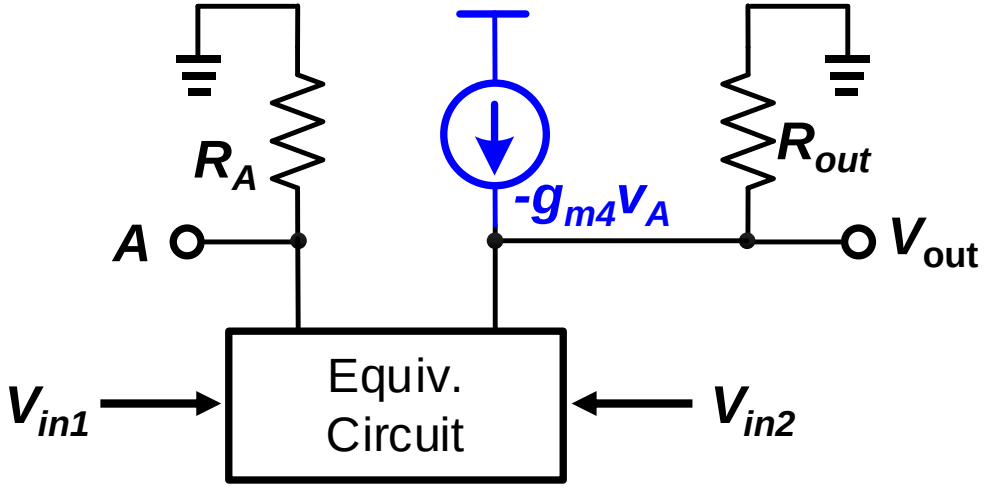


To be changed into Thevnin or Norton

Reflection of A to V_{out} Relation

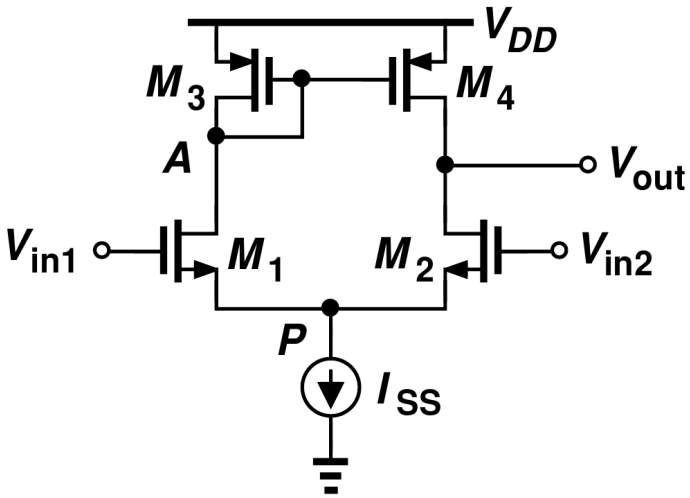


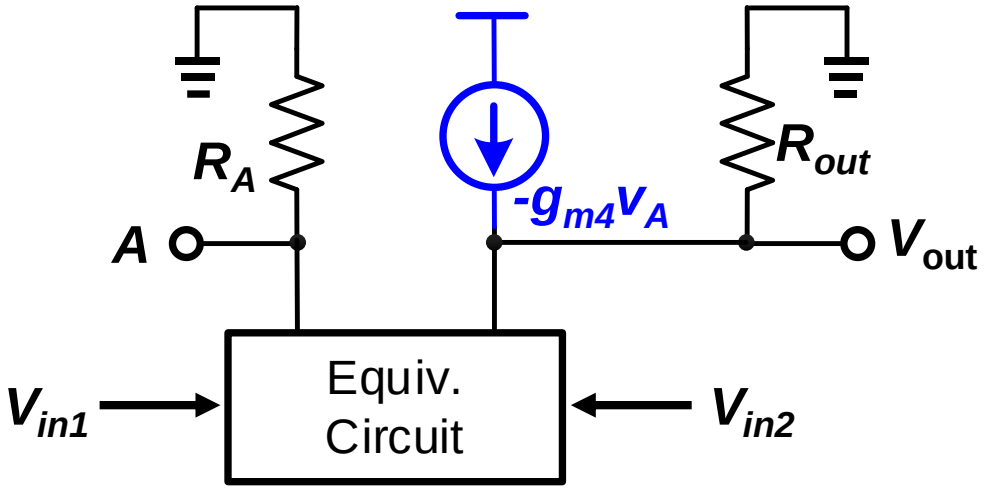




Determination of Impedance

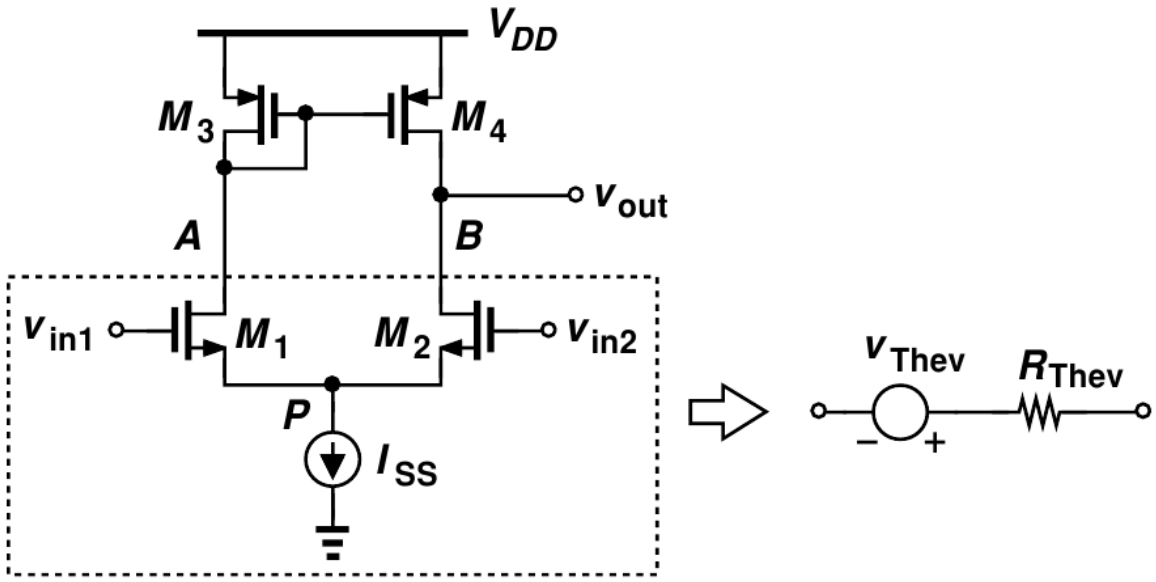
- R_A = ?, R_{out} = ?

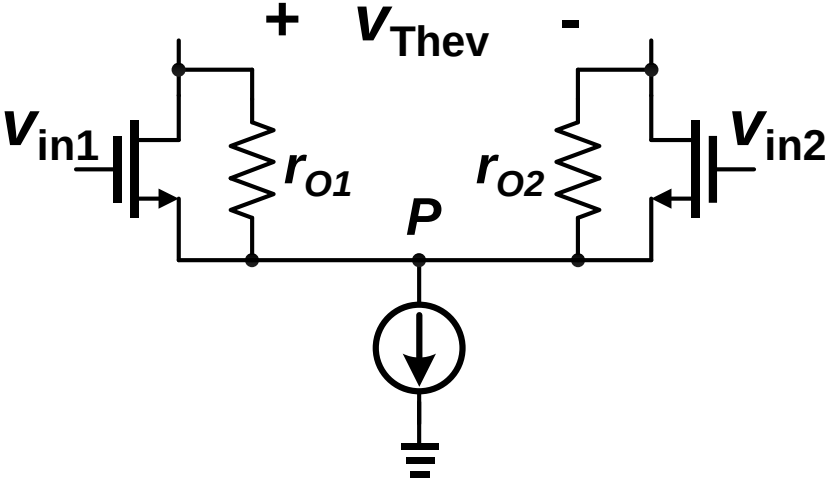


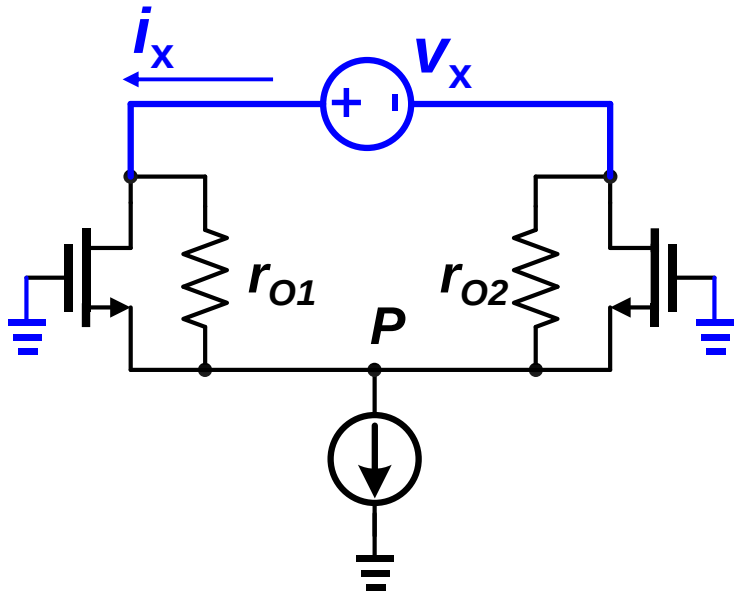


Applying Thevnin Circuit

- How to determine v_{Thev} and R_{Thev}?

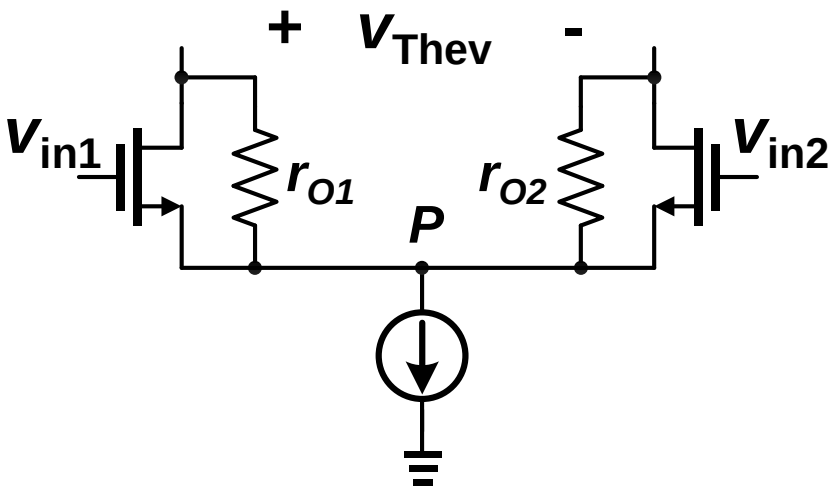


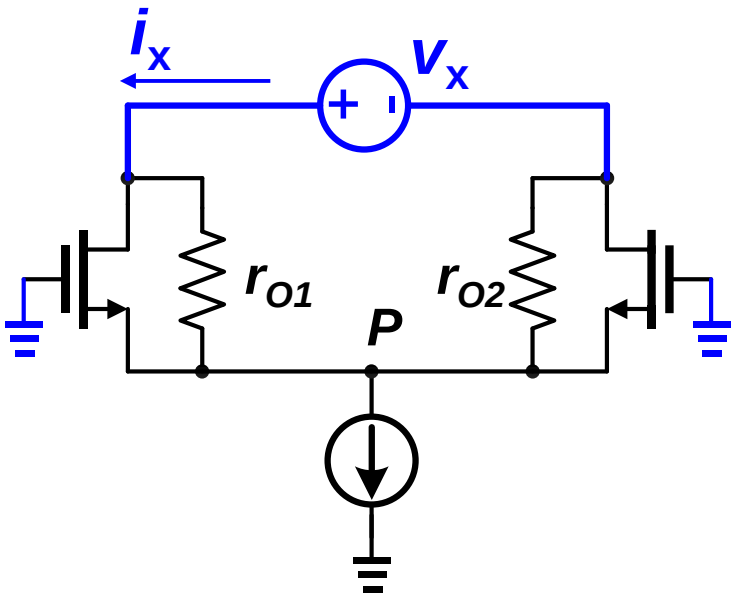




V_{Thev} and R_{Thev}

- You can utilize the half circuit with virtually grounding P
- With assuming $g_{m1} = g_{m21} = g_{mN}$ and $r_{O1} = r_{O2} = r_{ON}$,

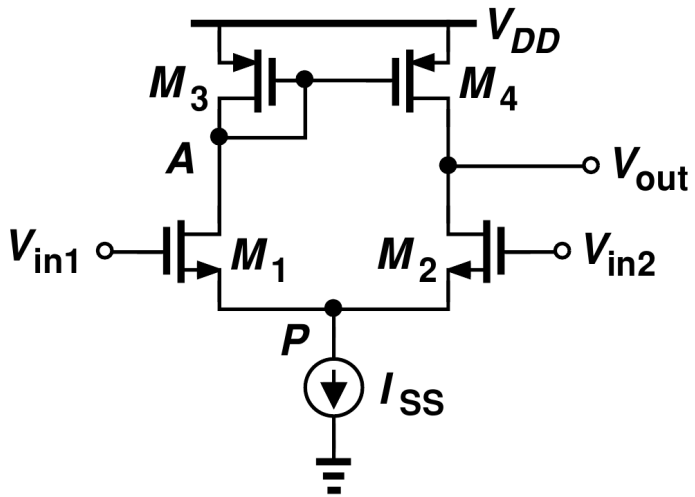


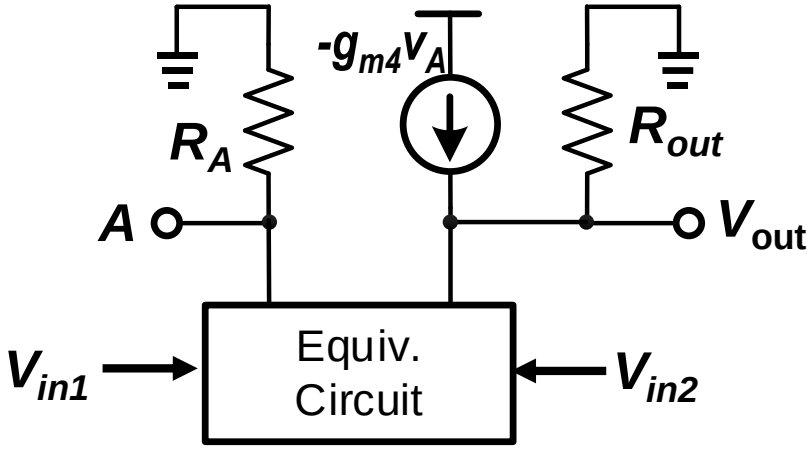


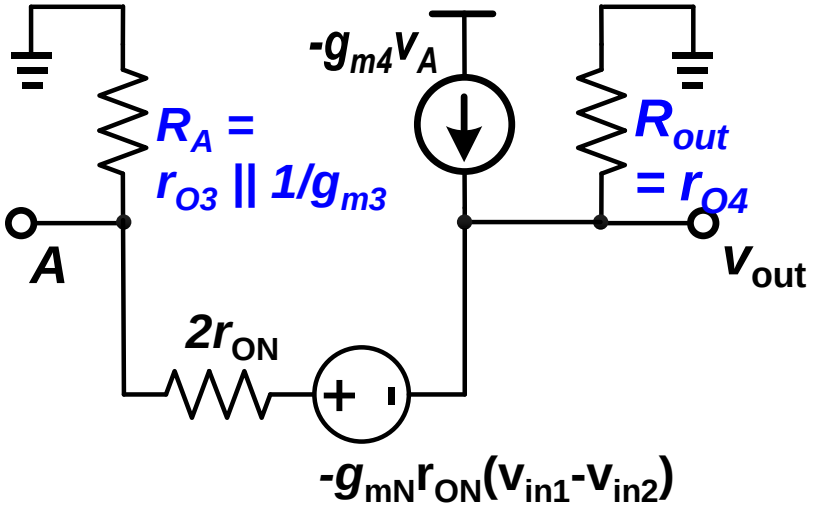
$$v_{Thev} = -g_{mN}r_{ON}(v_{in1}-v_{in2})$$

$$R_{Thev} = 2r_{ON}$$

Resultant Simplified Circuit



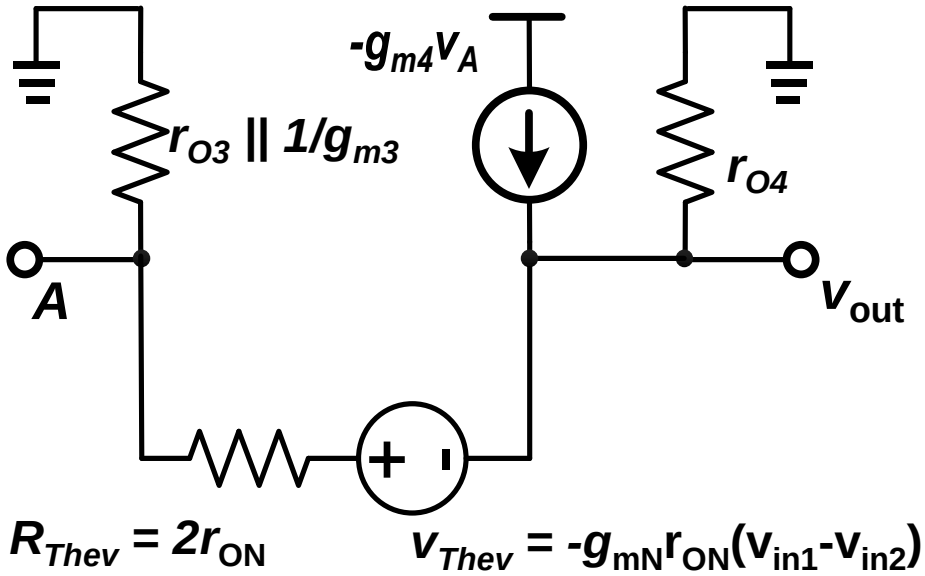




Now, We Can Obtain Gain! (cont'd)

- Applying KCL,

$$\frac{v_{out}}{r_{O4}} + \frac{v_{out} + v_{Thev}}{\dfrac{1}{g_{m3}} \left\| r_{O3} + R_{Thev}\right.} = -g_{m4} v_A$$



- v_A can be expressed with v_{Thev}

$$v_A = \frac{r_{O3} \| 1/g_{m3}}{r_{O3} \| 1/g_{m3} + R_{Thev}} v_{Thev}$$

- Thus, relationship between v_{Thev} and v_{out} can be obtained:

$$\left(g_{m4} \frac{\dfrac{1}{g_{m3}} \left\| r_{O3}\right.}{\dfrac{1}{g_{m3}} \left\| r_{O3} + R_{Thev}\right.} + \frac{1}{\dfrac{1}{g_{m3}} \left\| r_{O3} + R_{Thev}\right.} \right) (v_{out} + v_{Thev}) + \frac{v_{out}}{r_{O4}} = 0.$$

Now, We Can Obtain Gain! (cont'd)

- With
  - $v_{Thev} = g_{mN} r_{ON} (v_{in1} - v_{in2})$ and $R_{Thev} = 2_{rON}$,
  - $r_{O3} = r_{O4} = r_{OP}$ and $g_{m3} = g_{m4} = g_{mP}$

$$\left(g_{m4} \frac{\frac{1}{g_{m3}} \Big\| r_{O3}}{\frac{1}{g_{m3}} \Big\| r_{O3} + R_{Thev}} + \frac{1}{\frac{1}{g_{m3}} \Big\| r_{O3} + R_{Thev}} \right) (v_{out} + v_{Thev}) + \frac{v_{out}}{r_{O4}} = 0.$$

$$\left(g_{mP} \frac{r_{OP} \| 1/g_{mP}}{r_{OP} \| 1/g_{mP} + 2r_{ON}} + \frac{1}{r_{OP} \| 1/g_{mP} + 2r_{ON}} + \frac{1}{r_{OP}} \right) v_{out}$$

$$= \left(g_{mP} \frac{r_{OP} \| 1/g_{mP}}{r_{OP} \| 1/g_{mP} + 2r_{ON}} + \frac{1}{r_{OP} \| 1/g_{mP} + 2r_{ON}} \right) g_{mN} r_{oN} (v_{in1} - v_{in2})$$

Gain

- That is,

$$\frac{v_{out}}{v_{in1}-v_{in2}} = g_{mN} r_{oN} \frac{g_{mP}\dfrac{r_{OP}\|1/g_{mP}}{r_{OP}\|1/g_{mP}+2r_{ON}} + \dfrac{1}{r_{OP}\|1/g_{mP}+2r_{ON}}}{g_{mP}\dfrac{r_{OP}\|1/g_{mP}}{r_{OP}\|1/g_{mP}+2r_{ON}} + \dfrac{1}{r_{OP}\|1/g_{mP}+2r_{ON}} + \dfrac{1}{r_{OP}}}$$

- When we assume $1/g_{mP} << r_{OP}$ and $1/g_{mP} << r_{ON}$

$$\frac{v_{out}}{v_{in1}-v_{in2}} = g_{mN} r_{ON} \frac{\dfrac{1}{r_{ON}}}{\dfrac{1}{r_{ON}}+\dfrac{1}{r_{OP}}} = g_{mN}(r_{ON}\|r_{OP})$$

Can We Just.. ?

